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Explicit and Implicit Directional Information Transfer in Collective Motion

E. Ferrante[1,2], A. E. Turgut[1,2], C. Huepe[3], M. Birattari[1], M. Dorigo[1] and T. Wenseleers[2]

[1]IRIDIA, CoDE, Université Libre de Bruxelles, 50 Av. Franklin Roosevelt CP 194/6, 1050 Brussels, Belgium
[2]Laboratory for Entomology, Katholieke Universiteit Leuven, 59 Naamsestraat - bus 2466, 3000 Leuven, Belgium
[3]Northwestern Institute on Complex Systems, Northwestern University, Evanston, IL 60208, USA

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Extended Abstract

We study the cohesive coordinated collective motion of a group of mobile autonomous robots. We use virtual interactions between robots implemented via proximal control, which allows the robots to reach a stable formation using virtual potential functions (Turgut et al., 2008; Ferrante et al., 2011). The alignment component can be seen as a mechanism for directional information transfer (Sumpter et al., 2008). We refer here to information transfer in collective motion as the process through which robot orientation is transferred to its neighbors over time.

We consider here two information transfer mechanisms for collective motion in a group of mobile robots. The first one exploits information transfer through direct communication and requires robots equipped with proximity, orientation sensing and communication devices. We propose communication strategies that allow the robots informed about a desired direction of motion to influence the rest of the group (Couzin et al., 2005; Ferrante et al., 2011). The second mechanism consists of information transfer without the alignment component and communication (Ferrante et al., 2012), which can be used on simpler robots only equipped with proximity sensors. We developed a simple motion control mechanism that allows a group of robots to perform collective motion in a random direction without needing robots informed about a desired direction or an explicit alignment behavior: information among the robots is thus transferred indirectly.

Information transfer via communication We consider a case where some robots have a persistent desired direction of motion (desired direction A) which could, for example, represent the direction to a food source. There is also a second desired direction (desired direction B), only present during a time window which could, for example, represent the escape direction from a predator. Desired direction B is in conflict with A: it points in the opposite direction and has higher priority. The objective is to move the group in the direction that, at a given time, has the maximum priority, and to keep the group cohesive.

We proposed a self-adaptive communication strategy (SCS), that is an extension of two previously proposed strategies (Ferrante et al., 2011). In SCS, the robot sends an angle θ_{s_0} and receives angles θ_{s_i} from its k neighbors. It computes the average of the received angles: $\mathbf{h} = \frac{\sum_{i=0}^{k} e^{j\theta_{s_i}}}{\| \sum_{i=0}^{k} e^{j\theta_{s_i}} \|}$. The angle sent is: $\theta_{s_0} = \angle\left[w\mathbf{g} + (1-w)\mathbf{h}\right]$. The parameter $w \in [0,1]$ is the degree of confidence of the robot on the desired direction $\mathbf{g}$. Non-informed robots use $w = 0$ (they possess no information about $\mathbf{g}$). Robots informed about desired direction B use $w = 1$, which makes them stubborn. Robots informed about desired direction A increase w when they measure high level of consensus in the information received by the neighbors, and decrease it otherwise.

Figure 1a shows the distribution of the accuracy over time, which measures how close the group direction is to desired direction A. In these experiments, 1% of the robots is always informed about desired direction A. During the time window where an additional 1% of the robots is informed about desired direction B, the accuracy reaching 0 indicates that desired direction B is being followed. In the remaining part of the experiment, the group correctly follows desired direction A. This result has been validated on real robot experiments (Fig. 1b). In addition, we show that SCS results either in a better accuracy (Fig. 1a and Fig. 1b) or in a better group cohesion (Fig. 1c) than two previously proposed strategies, HCS and ICS. The full results are reported in Ferrante et al. (2011).

Information transfer without communication We study information transfer with no alignment behavior and no communication. Our approach is based on a novel Magnitude Dependent Motion Control (MDMC) method, used to compute the forward and angular speed of the robot. The two speeds depend on the magnitude and angle of $\mathbf{f}$, the vector resulting from proximal control that encodes the attraction and repulsion strenght from the neighbors. $\mathbf{f}_x$ and $\mathbf{f}_y$ denote the projection of $\mathbf{f}$ on the axis parallel (x) and perpendicular (y) to the direction of motion of the robot. In MDMC, the forward speed u is proportional to the x component: $u = K_1\mathbf{f}_x + U$, and the angular speed ω to the y component: $\omega = K_2\mathbf{f}_y$, where U is a forward biasing speed.

Figure 1 (second row) shows the results of experiments performed with simulated and real robots. MDMC is compared to the method used in Turgut et al. (2008): Magnitude Independent Motion Control (MIMC). In MIMC, the forward and angular speed do not depend on the magnitude of the vector $\mathbf{f}$ but just on its angle. Figure 1d shows the distribution of the order metric over time, which measures the degree of alignment in the group. MDMC achieves ordered motion without the alignment behavior

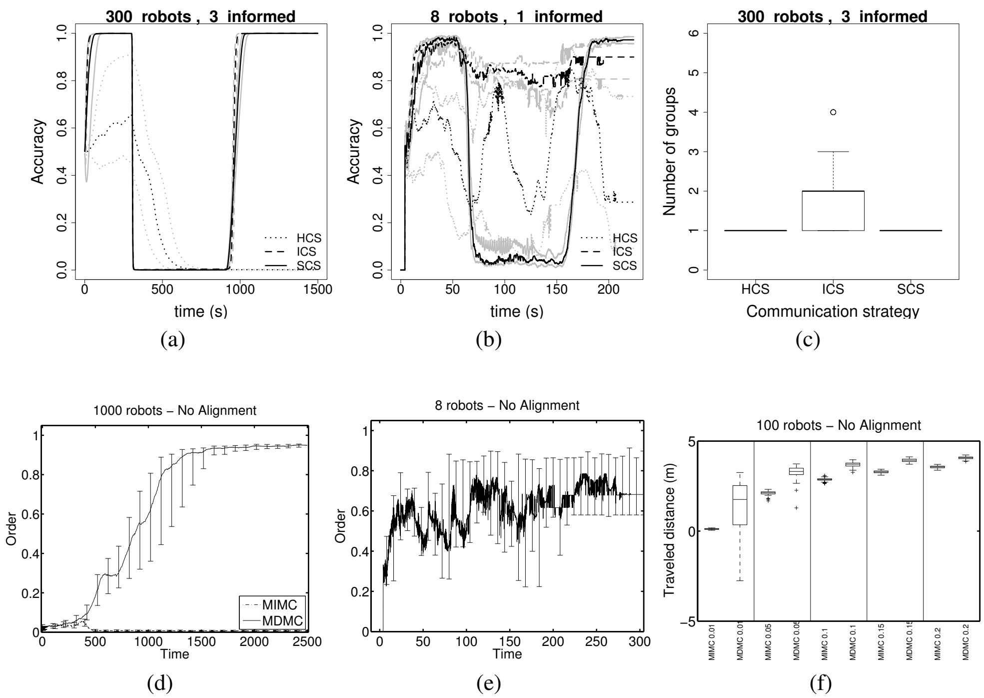

Figure 1: Experiments with simulated and real robots. Time dependent data is sampled every second. Black lines are the medians of the distribution, whereas grey lines (in (a), (b)) and error bars (in (d), (e)) represent the 25% and the 75% quartiles.

and without informed robots, whereas MIMC does requires informed robots or the alignment behavior. These conclusions are backed up by real robot experiments (Fig. 1e). Moreover, when a proportion of informed robots ($0.01, 0.05, 0.1, 0.15, 0.2$ as indicated in the plot) is introduced, the group is able to travel further along a desired direction of motion using MDMC than using the earlier MIMC method (Fig. 1f).

Discussion and conclusion We showed that the information needed to achieve collective motion can be transferred either directly or indirectly. Direct information transfer requires robots with orientation sensing and communication devices. We developed a communication strategy that can cope with two conflicting desired directions of motion. We also proposed a novel mechanism for robot motion that exploits indirect information transfer. This allows robots that lack the above mentioned capabilities to perform cohesive collective motion without communication, showing that implicit information transfer on the heading direction takes place even without communication. In future work, we will use information-theoretic metrics to measure information transfer more rigorously.

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References

Couzin, I. D., Krause, J., Franks, N. R., and Levin, S. A. (2005). Effective leadership and decision-making in animal groups on the move. *Nature*, 433:513–516.

Ferrante, E., Turgut, A. E., Huepe, C., Stranieri, A., Pinciroli, C., and Dorigo, M. (2012). Self-organized flocking with a mobile robot swarm: a novel motion control method. IridiaTr2012-003, Université Libre de Bruxelles, Belgium.

Ferrante, E., Turgut, A. E., Stranieri, A., Pinciroli, C., Birattari, M., and Dorigo, M. (2011). A self-adaptive communication strategy for flocking in stationary and non-stationary environments. IridiaTr2012-002, Université Libre de Bruxelles, Belgium.

Sumpter, D. J. T., Buhl, J., Biro, D., and Couzin, I. D. (2008). Information transfer in moving animal groups. *Theory in Biosciences*, 127(2):177–186.

Turgut, A. E., Çelikkanat, H., Gökçe, F., and Şahin, E. (2008). Self-organized flocking in mobile robot swarms. *Swarm Intelligence*, 2(2):97–120.